Verifying and Predicting Boiler Performance For Various Low Sulfur Coal Blends Using An Energy Balance Computer Program

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1.0 Introduction

Recent legislation at the state and national levels has forced electric utilities and other companies which burn fossil fuels to reduce their atmospheric emissions of sulfur compounds. The Federal Clean Air Act of 1970 and the Clean Air Act Amendment of 1990 are examples of national legislation which mandate lower emissions levels. At the state level, the Wisconsin Acid Rain Legislation of 1985 demands that by 1993 emissions of SO_2 not exceed 1.2 lb/MM BTU of fuel burned for fossil-fired plants in that state. Dairyland Power Cooperative, a Wisconsin electric utility, sought ways to meet these requirements for their coal-fired generating stations.

Dairyland Power's approach to meeting the Wisconsin requirements is to use a blend of low sulfur eastern and western coals. Various blends were recently tested to determine whether this method would meet the new emissions restrictions and still provide acceptable unit performance. For the Genoa Generating Station Unit 3, a 360 MW supercritical unit, several coal blends were tested. Some met the Wisconsin emissions requirements and Dairyland Power performance requirements; others did not.

Concurrent with this testing effort, Dairyland Power contracted with Performance Engineering, Inc. to construct an energy balance computer model of the Genoa Unit 3 boiler using the PEPSE computer program. This model would be used to verify the test results and be used as a predictive tool for further coal blend and plant performance studies.

Results of the coal blend testing are presented as well as the results of using the heat balance computer model. Comparisons of the model results to the actual test results are made. Differences in the two methods are given and discussed, and the confidence level of using the model for future boiler performance predictions is expressed.

2.0 Unit Description

Genoa 3, Unit 1 is a tangentially-fired Combustion Engineering supercritical boiler with combined circulation and double reheat. The furnace is a single cell and is fired with pulverized coal. Full load for the unit is approximately 360 MW at a steam flow of 2.35 x 10^6 lb/hr. Main steam and both reheats are at 1010 ^{o}F (design), with a main steam pressure of 3800 psia. The unit came on line in mid-1970.

Figure 1 shows an elevation schematic of the Genoa boiler.

3.0 Complying with the Clean Air Requirements

In 1985, Wisconsin passed legislation requiring companies burning fossil fuels to meet certain emissions restrictions. In particular, the requirements mandate that by 1993, emissions of SO_2 not exceed 1.2 lb/MM BTU of fuel burned. Companies that do not meet this requirement may purchase "credits" from other companies that exceed the requirement.

Dairyland Power Cooperative's approach to meeting the emissions standards for their coal-fired plants is to reduce the amount of sulfur in the fuel burned at their plants rather than installing expensive SO_2 removal equipment. To achieve this, various coal blends are being investigated which will not only meet emissions standards but provide an acceptable performance level. Historically, Dairyland's primary coal has been medium to high sulfur coal mined in southern Illinois. By utilizing low sulfur coals from the eastern and western U.S., they hope to meet the clean air requirements and the unit's performance requirements. This approach is ideally suited to Genoa 3 because of the lack of long-term coal contracts. Genoa gets a majority of its coal on the spot market.

4.0 Testing

Dairyland Power has embarked on a ambitious testing schedule, investigating the effect of various coal blends on plant emissions and performance. This testing began in 1990 with the testing of four different blends at 100% load. Table 1 presents these results.

The outcome of these tests was the discovery of a preliminary target coal which produced the desired emission levels and a suitable level of plant performance. This coal, an 80% blend of eastern coal from Kentucky and 20% western coal from Wyoming, provided reduced SO_2 levels close to the Wisconsin standards. Although this blend did not produce the lowest SO_2 levels, it did provide the optimum reduction of SO_2 while providing the required level of plant performance and acceptable levels of fly ash removal. The precipitator at Genoa is too small to provide adequate residence time for removal of the low sulfur fly ash, therefore, the fly ash resistivity must be increased by the presence of SO_3 in the flue gas to assure removal.

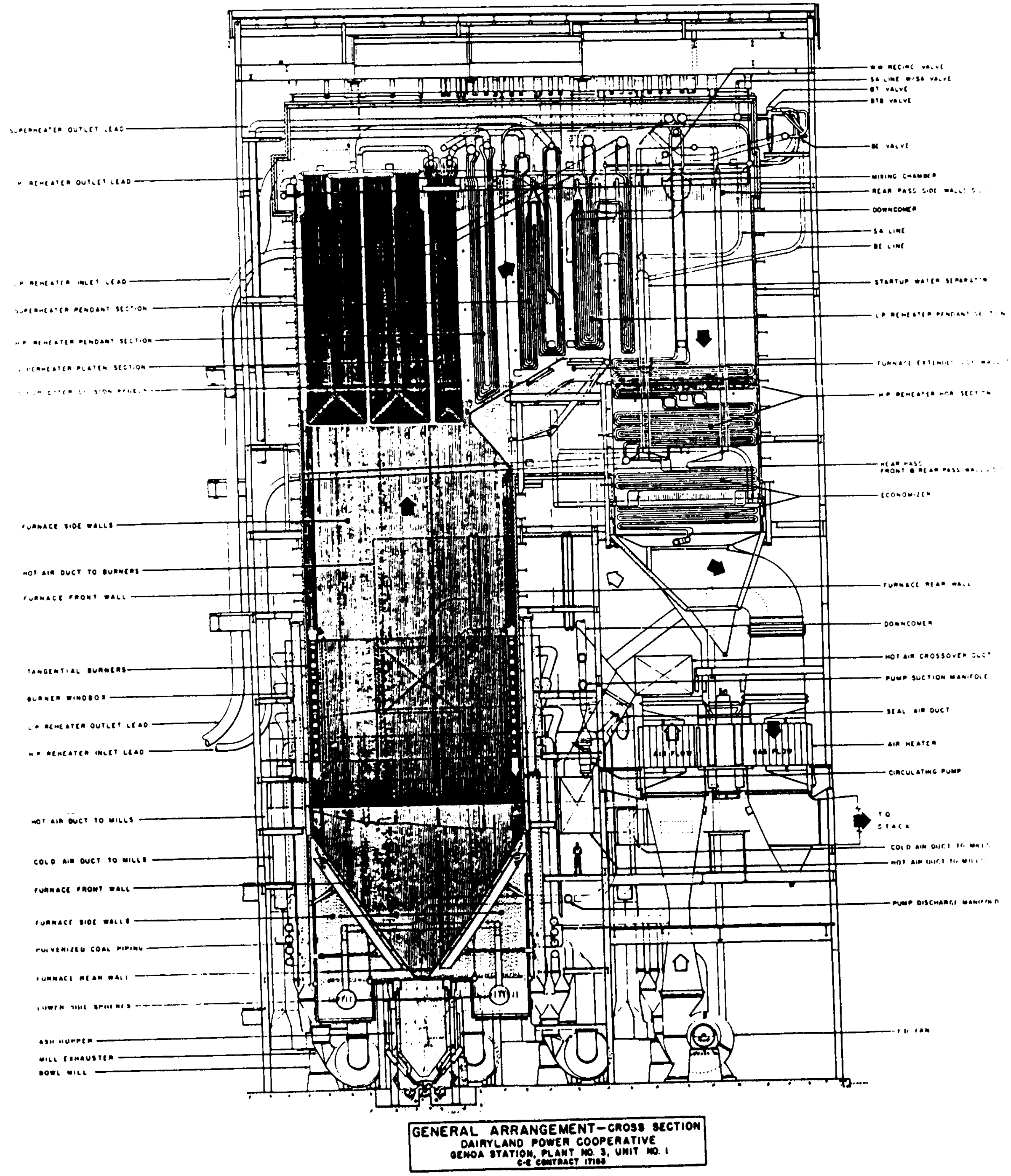

FIGURE 1

Genoa 3, Unit 1 Elevation Schematic

TABLE 1
1990 COAL BLEND TEST RESULTS

(August 1990)

	Coal Blend 100% Eastern 0% Western	Coal Blend 90% Eastern 10% Western	Coal Blend 80% Eastern 20% Western	Coal Blend 70% Eastern 30% Western
Gross Load (MW)	340.9	342.5	344.0	343.1
Net Plant HR (BTU/KWH)	9561	9586	9505	9549
Coal HHV (BTU/lb)	11691	11636	11209	10830
Excess Air (%)	29.6	29.4	29.3	29.6
Stack Temp (F)	333	314	326	331
SO2 (lb/MM BTU)	1.34	1.34	1.37	1.87
NOx (lb/MM BTU)	0.67	0.62	0.62	0.65
Boiler Efficiency (%)	86.76	86.15	86.96	85.98

In 1991 additional tests were conducted to further verify the target coal discovered in the 1990 tests and to determine the coal's effect on plant emissions and performance over the load range. Table 2 shows the results of these tests at 100% load. This target or "optimum" coal will be used to meet the clean air requirements. It is also the coal that will be used for the computer model studies.

5.0 Computer Model

Concurrent with the testing efforts, an energy balance computer model of the Genoa 3 boiler was developed using Version 56 of the PEPSE computer program[1]. The model was developed with significant complexity, including all major boiler components modeled using PEPSE's more rigorous and detailed design mode input option to allow detailed calculations of each boiler section's performance in addition to providing the boiler's overall performance and response.

Originally, this model was tuned to the boiler acceptance test[2] which was performed soon after the unit came on line. Three cases were used for tuning the model to the acceptance test and for model checkout: tests representing nominally 100% load, 75% load, and 50% load. The PEPSE model matches these test cases. A brief comparison of results is presented in Table 3. The model was later tuned to a 1991 performance test.

5.1 Model Description

A detailed model consisting of components representing each boiler section and heat transfer section was constructed. Figure 2 shows the PEPSE model constructed for the Genoa boiler (in the PEPSE man-machine interface graphics format).

5.2 Model Input

Input describing the geometry of a component, such as tube length or tube diameter, was obtained from a specific design drawing for that component of portion of the boiler containing that component. Input related to the performance of a component, such as air heater flue gas outlet temperature, was obtained from the Genoa test reports. Boundary conditions, including all temperatures, pressures, and flows which cross the system boundary, were also obtained from the test reports.

5.3 Model Tuning

Development of the model schematic and preparation of the model input are only a portion of the process of developing a useable PEPSE boiler model. Once built, the model must be

TABLE 2
COAL TEST RESULTS
(April 1991)

	Base Coal (Current Coal)	Optimum Blend (Proposed Coal)
Net Plant HR (BTU/KWH)	9376	8591
Coal HHV (BTU/lb)	10298	10290
SO2 (lb/MM BTU)	4.10	0.82
NOx (lb/MM BTU)	0.68	0.86

TABLE 3
ACCEPTANCE TEST RESULTS COMPARED WITH PEPSE RESULTS

Parameter	Results From Accept. Test 100% Load	PEPSE Results 100% Load	Results From Accept. Test 75% Load	PEPSE Results 75% Load	Results From Accept. Test 50% load	PEPSE Results 50% Load
TEMPERATURES (F)						
Main Steam	1006.0	1007.2	1000.5	1004.9	999.5	1006.3
Hot Reheat to LP1	999.0	1001.5	979.5	986.1	976.5	981.7
Hot Reheat to LP2	1001.0	1002.3	991.0	990.1	976.0	977.0
FW Exiting Econ	614.0	615.3	591.0	590.8	571.0	572.1
Pulverizer Out	140.0	140.0	140.0	140.0	140.0	140.0
Air from AH "A"	622.0	623.3	597.0	595.6	567.0	567.9
Air from AH "B"	626.0	627.4	604.0	602.4	566.0	566.7
Gas to Air Heaters *	705.5	715.4	673.5	665.8	632.0	630.4
Gas from Air Heaters *	311.0	313.4	311.5	293.9	290.0	272.7
Division Panel Out	785.0	785.3	768.0	769.5	762.0	764.2
Platen SH Out	894.5	895.5	859.0	863.2	868.5	874.1
PRESSURES (PSIA)						
Main Steam	3559.0	3559.7	3528.0	3529.2	3519.0	3517.0
Hot Reheat to LP1	1034.0	1033.0	830.0	829.4	617.0	617.8
Hot Reheat to LP2	375.0	374.1	287.0	286.4	217.0	216.6
Economizer Out	3742.0	3743.9	3640.0	3639.8	3565.0	3564.9
Division Panel Out	3675.0	3674.5	3602.0	3602.7	3558.0	3559.1
Platen SH Out	3637.0	3637.9	3578.0	3579.0	3545.0	3545.5
EFFICIENCIES						
Heat Loss Method	89.08	88.72	89.48	89.08	89.82	89.35
Input/Output Method	-	89.75	-	90.01	-	90.84

* Average for two heaters.

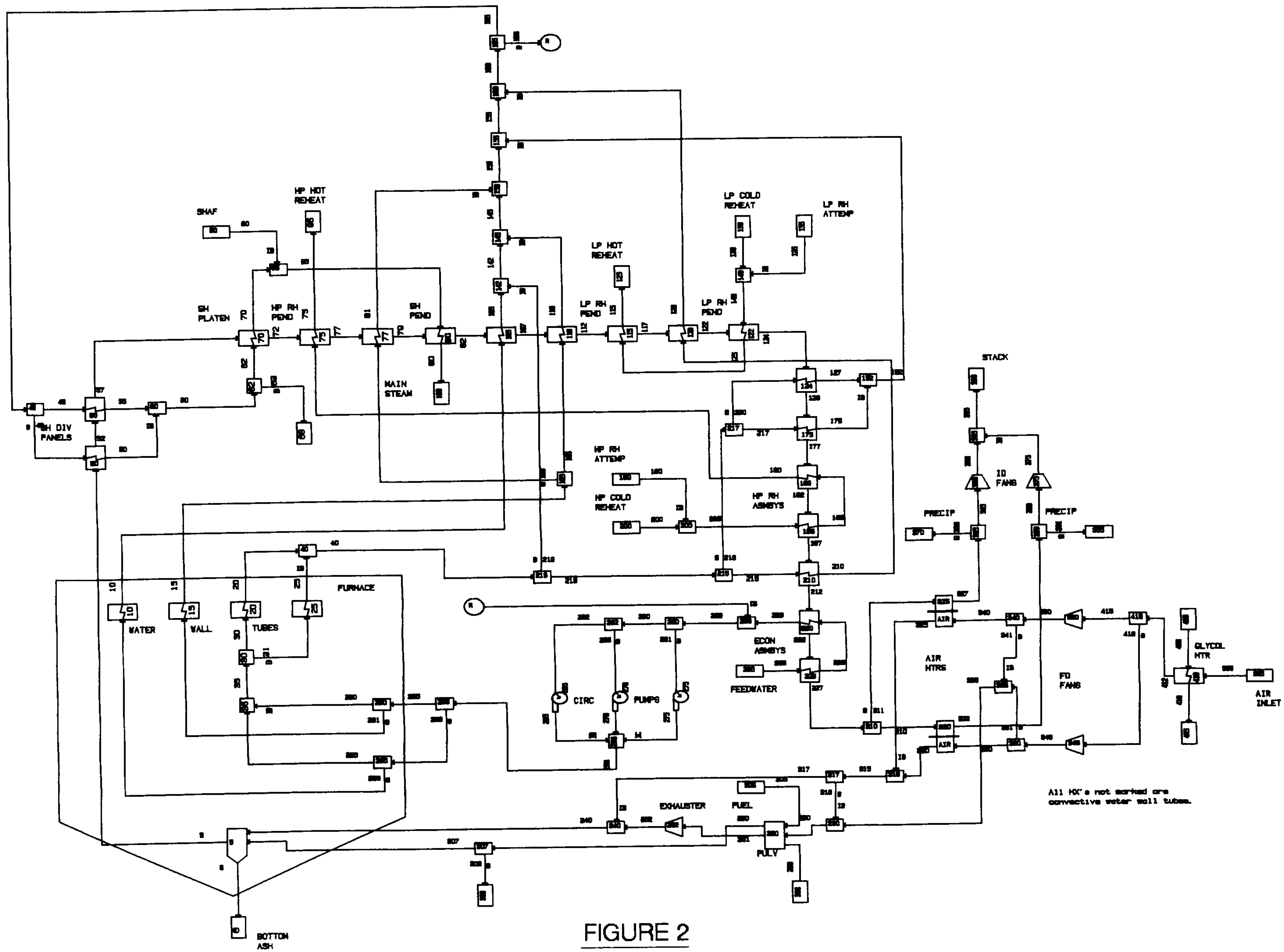

FIGURE 2
Genoa 3, Unit 1 PEPSE Boiler Model

"tuned" to match some set of performance criteria, the most common being the original design, the acceptance test results, or the results from a recent performance test. The Genoa boiler model was originally tuned to the acceptance test data to verify the PEPSE model and to establish a baseline performance. The model was later tuned to a set of performance data taken in 1991 to establish a current performance baseline.

Tuning is the process of modifying the PEPSE-calculated pressure drop characteristics and heat transfer characteristics to match a set of design conditions or measured plant conditions. In the design input mode, PEPSE's heat transfer components' pressure drops and heat transfer are calculated based on industry-accepted first principles calculations. Details of these calculations are given in the PEPSE theory manual[3]. These first principles calculations must be modified to account for the actual design or performance of the plant. The modifications, or tuning parameters, account for the boiler vendor's adjustments to boiler performance based on years of design and testing experience, or account for the deterioration, fouling, or other performance changes of the boiler sections over a period of time.

5.3.1 Tuning Process

Several factors are available to use as tuning parameters in PEPSE. For pressure drop tuning, the form loss coefficient (k), the friction factor (f), or a combined form loss and friction factor (f*L/D + k) may be modified to achieve the desired pressures throughout the boiler. For heat transfer tuning, the tube inside film coefficient, the tube outside film coefficient, the fouling resistance, the tube thermal conductivity, or a combined factor which represents the entire thermal resistance from the inside to the outside of the tube may be modified. In tuning Genoa to the performance data, combined factors were used.

A tuning parameter may be input directly, or it may represent a multiplier on the PEPSE-calculated value for that parameter. If input directly (i.e., direct input of a heat transfer coefficient), the value usually must be changed for each load because the actual value changes with load. If input as a multiplier, however (i.e., 85% of the PEPSE calculated value), the value is generally good for all loads or variations of a particular load. This is true because PEPSE is calculating the actual parameter based on the current load or condition while the tuning multiplier is modifying it based on the characteristics of the boiler.

For the Genoa model, tuning multipliers, rather than actual parameters, were used to tune the model. Table 4 shows the final tuning parameters used to tune the Genoa model to the acceptance test data. These factors changed only slightly

TABLE 4
Calculated Tuning Parameters and Values
(Acceptance Test Tuning)

Tuning Parameter	PEPSE Variable	Location	VALUES 100% LOAD NOMINAL	75% LOAD NOMINAL	50% LOAD NOMINAL	Value Used in Model *	REMARKS
Combined Friction Factor and Form Loss Coefficient	FRMLS	Component 55	-2.0954	-1.5005	-2.0884	Schedule	Also use for component 50
Combined Friction Factor and Form Loss Coefficient	FRMLS	Component 70	-5.3157	-4.2247	-3.0000	Schedule	
Combined Friction Factor and Form Loss Coefficient	FRMLS	Component 80	-10.5493	-9.6574	-9.7466	Schedule	
Combined Friction Factor and Form Loss Coefficient	FRMLS	Component 122	-4.8655	-3.9485	-3.5679	Schedule	Also use for component 115
Combined Friction Factor and Form Loss Coefficient	FRMLS	Component 185	-1.6248	-1.6543	-1.1000	Schedule	Also use for components 180 and 75
Combined Friction Factor and Form Loss Coefficient	FRMLS	Component 225	-6.4147	-9.3985	-12.7894	Schedule	Also use for component 220
Overall Heat Transfer Coefficient	HTTIRH	Component 55	-0.4200	-0.6129	-0.4363	Schedule	Also use for components 50
Overall Heat Transfer Coefficient	HTTIRH	Component 70	-0.4635	-0.4994	-0.4488	Schedule	
Overall Heat Transfer Coefficient	HTTIRH	Component 80	-0.8146	-0.8429	-0.7859	Schedule	

TABLE 4 (continued)
Calculated Tuning Parameters and Values
(Acceptance Test Tuning)

Tuning Parameter	PEPSE Variable	Location	100% LOAD NOMINAL	75% LOAD NOMINAL	50% LOAD NOMINAL	Value Used in Model *	REMARKS
Overall Heat Transfer Coefficient	HTTIRH	Component 122	-1.0798	-1.2227	-1.0877	Schedule	Also use for component 115
Overall Heat Transfer Coefficient	HTTIRH	Component 185	-0.6906	-0.7655	-0.6794	Schedule	Also use for components 180 and 75
Overall Heat Transfer Coefficient	HTTIRH	Component 225	-1.3206	-1.4002	-1.4318	Schedule	Also use for component 220
Overall Heat Transfer Coefficient	CHETEX	Component 320	104.47	120.32	127.74	Schedule	
Overall Heat Transfer Coefficient	CHETEX	Component 325	108.41	130.39	126.12	Schedule	

* All FRMLS coefficients were scheduled vs feedwater flow.
All HTTIRH coefficients were scheduled vs furnace exit gas flow.
All CHETEX coefficients were scheduled vs gas flow to heater.

when the model was tuned to the most recent performance test.

5.3.2 Data Inconsistency Resolution

A problem surfaced when using the data presented in the acceptance test report for tuning the model. The data caused too much heat to be delivered to the PEPSE boiler model system (or caused too little heat removal) for all test cases. This problem was first noticed during the initial tuning phase when all boiler outlet conditions were successfully matched except the gas temperatures to the air heaters. These temperatures were at times several hundred degrees higher than those reported in the acceptance test results.

Based on discussions with personnel at Dairyland Power, the coal flows reported in the acceptance test report were considered the most likely cause of the differing gas temperatures calculated by PEPSE. Coal flow measurements are difficult to obtain accurately, and their value affects the results significantly. A 1% error in coal flow translates into a 1% error in boiler performance. Coal flow measurement errors are commonly encountered in tuning PEPSE boiler models.

In order to determine the correct value of coal flow to the boiler system, a sensitivity study was performed to match the gas temperatures to the air heaters. The sensitivity study involved running a series of PEPSE cases at each load point using different coal flow rates. For each study, it was noted which value of coal flow provided the best match of the gas temperature entering the air heater. The coal flow which provided the best match was considered the correct test coal flow. Figure 3 shows the results of this study at 100% load.

6.0 Results and Conclusions

Table 5 presents a comparison of the test results and the PEPSE results for; (1) the 1991 performance test using the base (normal) coal for Genoa, and (2) the low-sulfur target (optimum) coal test performed late in 1991. As shown, the optimum coal contains significantly less sulfur than the base coal. PEPSE calculated performance is very close to the measured performance for both cases.

An energy balance computer program such as PEPSE can accurately calculate the thermodynamic performance of a unit when the fuel make-up is changed. This can provide a useful tool in predicting future unit performance without having to run costly or time consuming boiler tests.

<u>FIGURE 3</u>

Gas Temp to Air Heaters vs Coal Flow

(100% Load)

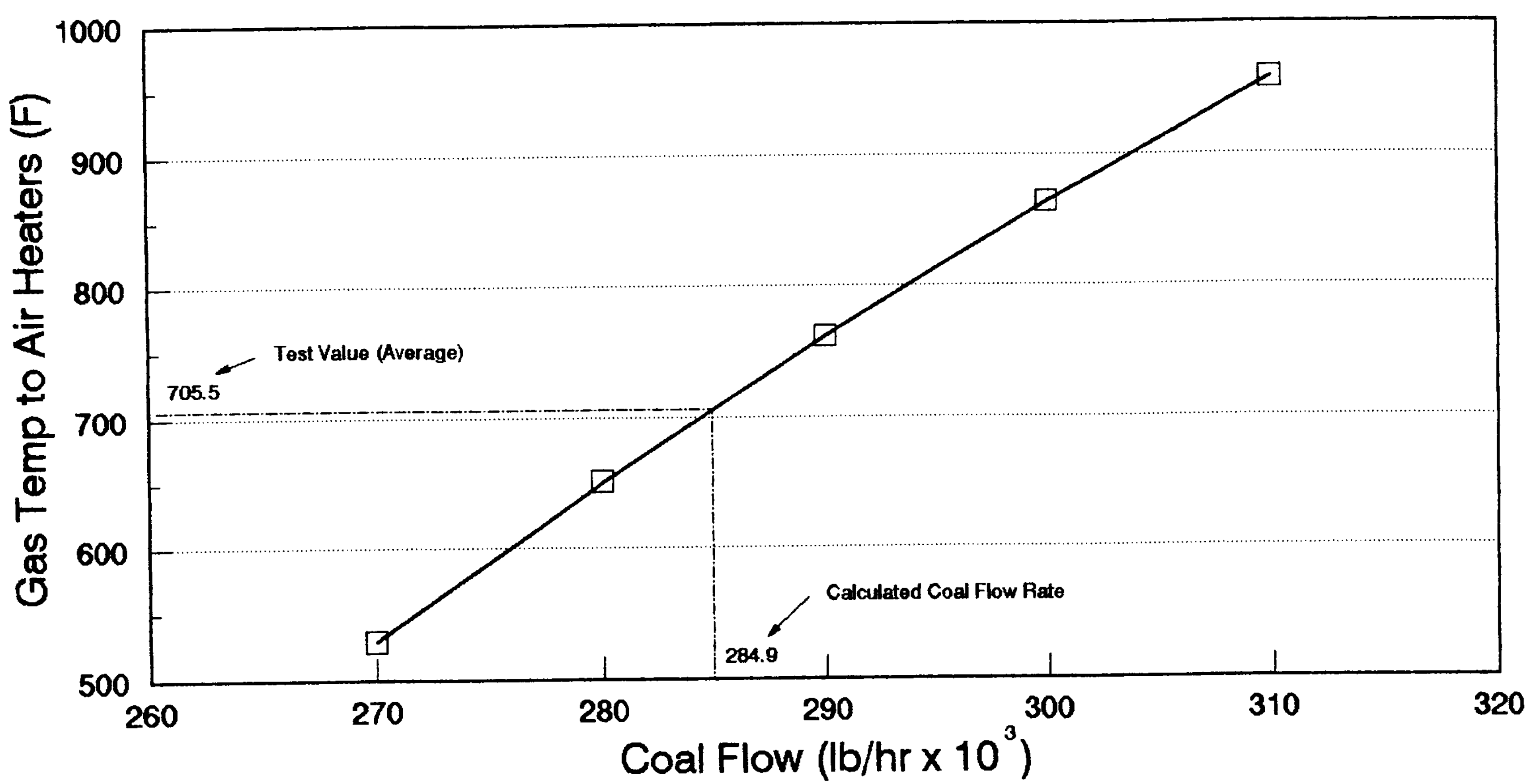

TABLE 5
Comparison of Results
Test vs PEPSE

	Base Coal (Current Coal)		Optimum Blend (Proposed Coal)	
	Actual	PEPSE	Actual	PEPSE
Steam Flow (klb/hr)	2596.8	2596.8	2089.8	2089.8
Coal Flow (klb/hr)	336.6	336.6	246.9	258.6
SH Spray Flow (klb/hr)	196.4	254.2	77.2	114.6
SH Temperature (F)	1005.0	1011.0	1009.0	995.6
HP RH Spray (klb/hr)	110.2	95.4	35.1	43.2
HP RH Temp (F)	1020.0	992.0	1004.0	991.0
LP RH Temp (F)	1014.0	1005.0	996.0	991.0
Water Wall Temp (F)	757.0	752.0	758.0	760.0
Econ Flue Out Temp (F)	791.0	748.0	737.0	721.0
AH Flue Out Temp (F)	350.0	311.0	333.0	306.0
Stack SO2 (lb/MMBTU)	-	-	0.82	0.82
Boiler Efficiency (%)	88.82	86.78	89.41	87.96
Fuel Analysis				
Carbon (%)	58.12	58.12	59.72	59.72
Hydrogen (%)	5.17	5.17	5.10	5.10
Sulfur (%)	2.40	2.40	0.49	0.49
Nitrogen (%)	1.72	1.72	1.75	1.75
Oxygen (%)	6.48	6.48	8.18	8.18
Moisture (%)	18.12	18.12	14.72	14.72
Ash (%)	7.99	7.99	10.04	10.04
HHV (BTU/lb)	10528	10528	10920	10920

By tuning a computer model such as PEPSE to test conditions, a high level of confidence in the model can be attained. Tuning to the latest performance test conditions can assure the model will behave closely to the current plant conditions if there has not been a significant time lapse since the last test.

PEPSE is a registered trademark of Hallibuton-NUS Corporation.

<u>References</u>

1. G. L. Minner, E. J. Hansen, W. C. Kettenacker, P. H. Klink, and G. C. Rice, "PEPSE Manual: User Input Description", Vol. I, Revision 16, January 31, 1991, NUS Corporation, Idaho Falls, Idaho.

2. Acceptance Test Report, Genoa #3, Unit #1 - Contract 17165, Project 950103, Section III, Description of Unit Tested.

3. G. L. Minner, E. J. Hansen, P. H. Klink, and W. C. Kettenacker, "PEPSE Manual: Engineering Model Description", Vol. II, Revision 8, January 31, 1991, NUS Corporation, Idaho Falls, Idaho.